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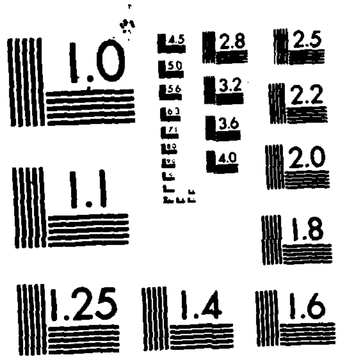

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ONR FINAL REPORT:

TECHNIQUES FOR COMPUTER-BASED TRAINING OF AIR INTERCEPT DECISION MAKING SKILLS

Allen Munro
Douglas M. Towne
James A. Cody
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October 1982

BEHAVIORAL TECHNOLOGY LABORATORIES
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Technical Report No. 101

BEHAVIORAL TECHNOLOGY LABORATORIES
Department of Psychology
University of Southern California

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techniques be used for training to be effective. Several dynamic skill tasks were studied, and a laboratory analog to the Air Intercept Controller task was developed for experimental use. The experiments conducted showed that intrusive instruction is less effective for such simulation training than is non-intrusive instruction. Experiments on the use of voice input and voice output devices for such training produced mixed results, suggesting that current low-cost technologies for voice I/O are approaching the acceptability threshold for this type of application.

ABSTRACT

This is the Final Report for Contract N00014-80-C-0164, covering a period of two and three-quarter years, from February 1980 through October 1982. Research was performed on topics associated with computer based training of dynamic skill tasks. Training for such tasks is to be distinguished from the teaching of fact systems, the training domain most heavily studied in computer based instruction applications. It was hypothesized that the attentional demands of dynamic skill simulation training require that special instructional techniques be used for training to be effective. Several dynamic skill tasks were studied, and a laboratory analog to the Air Intercept Controller task was developed for experimental use. The experiments conducted showed that intrusive instruction is less effective for such simulation training than is non-intrusive instruction. Experiments on the use of voice input and voice output devices for such training produced mixed results, suggesting that current low-cost technologies for voice I/O are approaching the acceptability threshold for this type of application.

ACKNOWLEDGEMENTS

The research described here was performed under Office of Naval Research Contract N00014-80-C-0164. Thanks are due to Henry Halff and Marshall Farr for support and advice. We thank Robert Breaux for advice and for access to training materials that helped solidify our understanding of the Air Intercept Controller task. We also thank Bob Lawson of the Office of Naval Research, Pasadena, for assistance in arranging for the observation of Air Intercept Controllers at work at the Pacific Missle Test Center, Pt. Magu, and in training at the Fleet Combat Training Center, Pacific.

Early plans for the AIC experimental simulation training system described here were influenced by discussions with Michael Grady and Robin Halley of Logicon. Professors Robert Alt and Fred Shima and Dean Virginia Pfiffner of El Camino College assisted in the recruitment of student subjects from their respective campuses in the first experiment. In addition to the authors of this final report, Pierre Blais, Michael R. Fehling, and Mark C. Johnson contributed to the research.

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The Research Issues

Decreased costs and increased performance for dedicated microcomputer-based simulation training systems will ensure that these systems will be more widely implemented than in the past. The prospect of such widespread implementation motivates the study of the effective use of such systems for the training of real-time, event-driven skills. The objective of this research was to develop an experimental computer-based training system and to conduct a number of experiments in dynamic skill training using the system. One set of experiments tested different approaches to giving the student information about the correctness of his performance during training. A second set of experiments focused on the problems and potentials of the use of voice input and voice output technologies in computer based training.

Simulators have long been known to provide effective practice. Transfer to actual tasks has been demonstrated (Orlansky and Spring, 1975). We believe that dynamic skill simulators can be even more effective trainers if they provide instructional functions in addition to the presentation of simulated practice episodes. The computers that control a simulation should also be able to play a role in guiding the training process. They should be able to interactively tutor the student, to select and control appropriate simulated problems, and to give the stude t useful instructional feedback during training.

At present, little is known about what techniques are likely to prove most effective in training dynamic skills. The range of techniques that could be applied through computer controlled training has not been explored. One stimulus for this research project was the expectation that fact system instruction techniques taken from conventional computer assisted instruction (CAI) would not prove to be an effective means of designing computer based dynamic skill training systems.

A central issue of concern in the project was to explore methods for mixing instruction and dynamic skill simulation practice. In conventional CAI for fact systems, student responses are typically required only after the system has finished making some presentation to the student. When the student responds, the system evaluates the response and then reacts appropriately. After making a response, a student's attention is typically directed to the system, in expectation of evaluative feedback or instruction relevant to the response just made. In dynamic skill practice sessions, in contrast, students typically expect further simulation responses from the system in reaction to their inputs. Their attention is directed to the simulated events, not to tutorial feedback. How can such instruction be effectively combined with simulation practice? The first series of experiments was designed to address this issue.

An Experimental Dynamic Skill Simulation Training System

One of the first project requirements was to develop a dynamic skill task for use in the laboratory. A number of Navy tasks were studied with an eye to producing a microcomputer simulation for training research. The following jobs were studied: Ground Controlled Approach (GCA) Controller, Landing Signal Officer (LSO), and Air Intercept Controller (AIC). The AIC task was selected because it offered the opportunity to train an attention-demanding task that could be simulated with relatively simple and inexpensive displays and controls.

The AIC dynamic skills trainer program simulates a videogame-like task similar to that of an air intercept controller. The task requires that the student observe blips representing aircraft detected by radar, and then use a joystick and special function keys to label those blips. The keyboard is also used to communicate with the simulated pilots of the aircraft to get fuel and weapons status and to send instructions to intercept and fire at enemy aircraft. Students are trained on the task in a single training session.

A student training episode has two major components. The first is a pre-training session, in which the student is introduced to the task and to the activities that comprise the skill. The second is a practice training session, in which the student

receives a combination of tutorial and simulated practice. The tutorial messages do not follow practice problems, but are presented during them. One research focus was how to mix practice and tutorial instruction effectively.

In the pretraining session students watch a computer-controlled videotape demonstration of the task with narrated instructions. Then brief explanations of each of the controls available to the student are presented in text format on the simulated control console. After reading each explanation, the student is required to briefly interact with a simple simulation that requires the exercise of the function just discussed.

During the practice training session, the student uses the techniques presented in the pre-training to play the air intercept simulation game. During this training phase, the system records student actions, the occurence of simulated events, student errors, and tutorial interactions with the student.

The training system was implemented using an Apple II system with 64K bytes of RAM, a hard disc drive, a real-time clock interface, a joystick, and external 80-column video display terminal, a videocassette controller, and interfaces for two different voice output devices. The student had three display screens: one for the videotaped instructions, an 80-column text display, and an Apple Graphics display screen. In some experiments, the student wore a

headphone that was connected to four sound sources: the videotape audio, the Apple's speaker, and the two computer voice output devices.

The same basic hardware configuration and core training program, described in technical report ONR-96, were used to implement a number of experiments.

Technical Report No. ONR-96

Allen Munro, Douglas M. Towne, & Michael R. Fehling, An Experimental System for Research on Dynamic Skills Training, September 1981

Academic research on computer based instruction (CBI) has dealt largely with CBI of knowledge systems, coherent bodies of essentially propositional knowledge. Little research has been performed on techniques for effective CBI of dynamic skills, those amalgams of perceptual, motor, and decision-making skills that are required by many real-time event-driven tasks. The demands of dynamic skill training on student processing resources are different from those of knowledge system teaching. These differences suggest that the techniques found to be effective in conventional CBI may not be applicable to dynamic skill training CBI. Two classes of research issues to be explored are techniques for presentation of simulation practice and methods for providing effective instructional feedback.

A microcomputer-based experimental simulation training system for research on dynamic skill training is described. Experimental subjects are taught to perform a simulation task based on the job of an air intercept controller. The training program permits controlled differences in instructional treatment for different groups of students, in order to explore empirical issues in dynamic skill training.

Intrusion in Dynamic Skill Instruction

Dynamic skill training is characterized by continuous involvment of both the computer system and the student. There is no clear exchange of turns between the computer and the student as there is in conventional "fact system" computer-based instruction. The student can enter a response at the same time that the simulation display is changed. Because the student is always busy with the task, there is no surrendering of the student's turn in order for the computer to instruct. In such an instructional system, how can instruction be integrated with simulation practice?

Two approaches to providing informative feedback in dynamic skill training were compared in a computer based training experiment. The first approach was to provide corrective instruction as soon as the student made a mistake during simulated practice training. This was called the intrusive instruction mode. The second approach was to signal the student that an instructional message was available whenever he or she made a mistake, but not to present the instruction until the student requested it. This was the non-intrusive instruction mode.

Two groups of students were trained to perform the simulated air intercept control task. Each group of students received the same pre-training and worked the same practice problems. One group received intrusive and the other non-intrusive instruction. The non-

intrusive group made significantly fewer errors during practice, but time spent on problems was not significantly different for the two groups. Analysis of errors by type showed that both important and less important aspects of performance were significantly affected by the intrusiveness variable, but that basic motor skills did not seem to be affected by intrusiveness. Instead, intrusive instruction appears to reduce cognitive performance on the task.

These results can be interpreted in light of an attentional demand hypothesis. In a complex dynamic skill training session, most of a student's cognitive processing resources are likely to be allocated to attending to and responding to the task itself. If the task is suddenly intruded upon by an instructional message, the intrusion will demand additional processing resources to perform the attentional shift. This surge in processing resource demand is likely to interfere with the normal learning and performance process. If the disruption occurs at a point in the task when a large percentage of cognitive resources are already committed, then either attention to instruction or performance on the task is likely to suffer.

Technical Report No. ONR-97

Allen Munro, Michael R. Fehling, Pierre Blais, & Douglas M. Towne, Intrusive and Non-Intrusive Instruction in Dynamic Skill Training, October, 1981.

ABSTRACT

A distinction is drawn between computer based instruction of knowledge systems and computer based instruction of dynamic skills. There is reason to expect that the findings of research on knowledge system instruction will not apply universally to dynamic skill instruction. In particular, a theory of cognitive resource demand suggests that the principle of immediate instructional feedback may not apply in dynamic skill training. Because students in dynamic skill training are often heavily loaded with processing demands, instructional feedback must be postponed until the students have sufficient free resources to process it. This hypothesis was tested in an experiment in computer based instruction. One group of students received instructional feedback upon request, while a second group received feedback under program control. The group with control over feedback made significantly fewer errors in training than did the group that did not control timing of the instructional feedback messages.

Computer-based Voice Instruction and Intrusion

One concern about the results of the first study was that the task was so difficult that students processing resources were heavily overloaded. Would the intrusive instruction effect hold up when the task was less demanding? A revised, simplified version of the AIC task was developed in order to replicate the previous findings in a simpler task environment.

The second issue addressed in the new study was the consequences of computer generated voice output in simulation and instruction. The experiment addressed the question: Are currently available low cost voice output devices useful for instruction in dynamic skill training? Many dynamic skills require the use of voice. A natural approach to computer based training of these skills is to make use of computer generated voice. The experiment compared instruction by computer generated voice with text instruction.

Two very distinguishable computer generated voice output devices were used in the voice conditions of the simulation training. A device employing a pre-recorded digital representation of actual human speech was used to simulate the vocal responses of the pilots of the controlled aircraft. This device produced very clear, quite natural-sounding speech. A text-to-speech synthesis device was used to deliver instructional messages to students in the voice training group. Students in the text group read the same messages. The

speech quality of the text-to-speech synthesizer was much lower than that from the device that simulated the pilots' voices. During pre-training, the students in the voice group were familiarized with the messages by listening to the computer-generated voice while reading the messages. They were given the option of repeating each message until they understood and heard them clearly.

Students in the intrusive instruction groups made more errors than those in the non-intrusive instruction groups. Analysis of crucial and non-crucial errors revealed that there was a significant difference in number of errors only for non-crucial errors. This result contrasts with that of the previous study, in which crucial errors also were significantly greater for the intrusive than for the non-intrusive group. It is likely that intrusive group students were able to perform as well as non-intrusive students on the crucial subtasks because the revised AIC task was simpler than the original task.

Voice instruction resulted in significantly more errors than did text instruction. The result suggests that the low-quality voice output equipment used in this experiment is not appropriate for dynamic skill training tasks such as the AIC task. It remains to be determined whether a more intelligible voice output device would result in performance equal to or superior to text instruction performance.

Technical Report No. ONR-99

Allen Munro, James Cody, and Douglas M. Towne, Instruction Mode Instruction Instrusiveness in Dynamic Skill Training, August 1982.

ABSTRACT

Unlike computer based instruction of knowledge systems, instructional feedback for dynamic skill training has been found to be most effective when the student chooses when and if feedback is to be received (Munro, Fehling, Blais, & Towne, 1981). Because students in dynamic skill training are often heavily loaded with processing demands, instructional feedback must be postponed until students have sufficient free resources to process it. The present study attempts to replicate these findings using a simpler task. The second factor in the present study is the effectiveness of computer generated voice output in instruction and simulation in dynamic skill training. These hypotheses were tested in an experiment in computer based instruction. Both the intrusiveness and delivery mode (text-voice) factors had statistically significant effects on student errors. The group which performed the best received feedback in a textual mode and had control over when and if they were to receive feedback. The second best group received feedback in a computer voice mode and had control over when and if they were to receive feedback. The third best group received immediate feedback to errors and feedback that was in a textual mode. The group with the poorest performance received immediate feedback to errors and feedback that was in a computer voice mode. The results suggest (1) that instruction in dynamic skill should be non-intrusive, and (2) that current inexpensive voice synthesis technology is not appropriate for dynamic skill training.

Voice Input in Dynamic Skill Training

Military team performance commonly requires the use of voice communications among team members. During an air intercept control mission, for example, a team including the Air Intercept Controller (AIC), the Ships Weapons Controller (SWC), and the Tactical Action Officer (TAO) must work in a complementary fashion, together with other members of the shipboard control team, to advise the pilots of Combat Air Patrol (CAP) aircraft. Communication among these team members is largely conducted by voice. The armed forces ordinarily prescribe the use of voice brevity codes for team member communications in contexts such as air intercept control. The use of such codes helps to ensure the passing of unambiguous messages. It has an additional advantage for the cause of computer based training. Current voice understanding technologies require that the vocal responses to be received by a computer-based voice input system be part of a finite, pre-trained set of utterances. The use of voice brevity codes in military training thus makes those tasks appropriate for computer based training.

Voice has been shown to provide a more effective means of communication between team members working on a common problem than other techniques such as writing, typing, or sending diagrams. See, for example, the work of Chapanis (1975; Chapanis, Parrish,

Ochsman, & Weeks, 1977). To attempt computer-based team training of tasks that call for verbal communication by replacing that communication with a different form of communication more easily monitored by the computer would be a mistake. Substituting keyboard entry for voice would make it very easy for the computer-based training system to monitor team member communications. Unfortunately, it would also make the team's task very unnatural and, probably, very difficult.

The use of computer voice input in computer based training poses significant methodological issues. How can the computer system be reasonably certain that its perceptions of student communications are reasonably congruent with those of the students? That is, if speaker A says something to addressee B, how can one be reasonably certain that what the system hears is close to what B hears? One reason to expect recognition problems is that even the best of the commercially available systems is likely to make many more recognition errors than would take place with keyboard entry. A much more compelling reason to expect problems, however, is that students will often not restrict themselves to the required voice brevity codes in speaking. Since only the pre-established voice codes can be taught to the voice recognition system, innovative voice inputs will result in either incorrect recognitions or failures to recognize.

One response to this dilemma is to avoid the use of computer-

based training (CBT) for team training that requires voice communications. This would be an unfortunate choice, in that it would forsake the well-established advantages of CBT, such as accurate monitoring and record keeping, untiring individual attention, and reduced training personnel requirements. To investigate this issue, a pilot study has been conducted to explore the differences in performance in single subjects on a task using either a keyboard or a voice recognition system. A gunnery exercise game developed by Greitzer, Hershman, and Kelly(1981, Kelly and Greitzer, 1982) and adapted to Apple Pascal by Halff (personal communication) was used, with minor modifications. In the exercise it is necessary for the student to fire missles at an optimal point in time to receive the maximum points possible. If a missle is sent too soon, the missle splashes into the ocean and misses its target. If it is fired too late, points are lost. This exercise should be a sufficient test of the viability of using computer voice recognition devices in the analysis of military team training tasks.

Method

Subjects. Subjects were paid volunteers who responded to posted notices at the University of Southern California. Thirty students participated in the experiment. All completed the experiment. Students were assigned to one of the two groups in alternating sets-of-five order as they arrived for the experiment. Each student received four dollars for participating in the experiment.

Procedure. Subjects were run individually in the experiment. Completion of the exercise session required from forty to fifty minutes. All subjects were given an information sheet which explained the task. The instructions were the same except where it pertained to the sending of the missle (i.e., via keyboard or voice). In the game, the student gunner views a radar display in which his or her own ship is in the center. Concentric rings mark the twenty- and forty-mile ranges from the ship. The radar displays incoming attacking aircraft (bogeys). The bearings of these incoming bogeys are displayed on the radar screen as two-digit numbers near the point of origin of each bogey on the radar screen.

The task of the gunnery student is to observe the incoming bogeys and to fire defensive missiles at the appropriate time. The apropriate time is determined by the speed of the attacking bogey. If an incoming attacker is moving very quickly, a countering missile must be fired well in advance of the time it would be fired for a slower bogey. Students estimate bogey speed based on the displayed distance covered between radar updates.

In one version of the game, the student fires a countering missile simply by keying in the bearing of the bogey on an auxiliary keyboard. A ship-to-air missile is then fired in that direction. These missiles all have the same constant speed and

limited range. If the missile is fired too early, it will reach the limit of its range (20 miles) and fall into the ocean before it encounters its target. If the missile is fired late, the bogey will be unacceptably close when it is downed. If the missile is not fired at all, the bogey will hit the ship.

Students receive two points for getting a bogey just at the twenty mile range and one point for downing a bogey in less than that range. Students lose twelve points if their ship is hit. Task difficulty is increased by increasing the number and speed of the attacking enemy aircraft.

In the voice input version of the game, the gunnery student does not use the keyboard. Instead, the student simply says the number, expressed as a sequence of digits, followed by the word "Launch" to send a ship-to-air missile against a bogey at a particular bearing. Editing of the input numbers is permitted by either using the word "Cancel" which erases all digits entered or by entering more digits which scroll the previous digits to the left (i.e., the right-most digit was the last one spoken).

Before a student plays the Air Defense Command (ADC) game using the voice input device (the Auricle I), he must first "train" the Auricle to understand his spoken commands. Since the Auricle is limited to speaker-specific recognition, each student must train the Auricle to understand their particular voice. The

student is prompted with each command word and repeats this command aloud three times. After all twelve command words (Zero through Nine, Launch, and Cancel) have been added to the Auricle's memory, the student is asked to repeat each command one more time as a last check to see if the Auricle will understand each command during the ADC game.

All subjects were guided by the experimenter through a practice game which consisted of eighteen bogeys. Next the students participated in two complete games on their own. Each game consisted of fifty-four bogeys. Data was collected automatically by the computer. Data consisted of the achieved score by the students on each game.

Results

The scores for the two training practice games were summed and an analysis of variance was performed. See Table 1. Although no significant difference was found between the voice input and keyboard input groups, the mean scores for the two groups are quite divergent, 89 points for the keyboard group and -24 for the voice group. Visual inspection of the data suggests that a number of students in the voice group performed poorly in the first practice game but improved in the second one. A second analysis was performed, using only the scores from the second game. See Table 2. The results are, again, not significant. The keyboard group scored a mean of 54 points, while the voice group scored 9 points

in this game. This is an improvement over the negative mean score of the voice group for the combined games, but still rather unimpressive in comparison with the keyboard entry group.

Inspection of the performance data for the second practice game shows that three of the students in the voice group had severe performance difficulties throughout the experiment, while the other twelve had learned how to use the system effectively by the time of the second practice game. Those three students earned negative scores on the second practice game. If their data is removed, the keyboard and voice input groups appear to have performed almost identically, with the voice group scoring 51 points on the second game. These results tentatively suggest that there is no significant difference between sending commands by voice and sending commands by keyboard in this task for most of the students.

Discussion

Results from the pilot study indicate that available, moderate cost voice recognition systems may adequately replace keyboard technology for interactive training of dynamic skills. Twenty percent of the voice students did have an extremely poor score, which may be due to inconsistencies in the pronunciation of the vocabulary items. Those students who spoke in a calm tone of voice during the template creation process, but an excited tone of voice during the recognition phase, suffered poorer recognition results than students who spoke consistently. It is possible that this

problem could be ameliorated by creating a more naturalistic setting for template creation.

Computer-relayed Voice Communications in Military Team Training

Military team training offers a desirable environment in which to study the feasibility of voice input and output technologies for computer based instruction. Military team training tasks are usually well defined, making them suitable for computer based instruction. Voice communications in these tasks are by means of voice brevity codes, prescribed utterances from a restricted vocabulary. Because the vocabulary is restricted, a voice recognition system can be trained in the permitted utterances for each team member. The use of these codes by students will be encouraged through the use of voice-input training systems. Because voice recognition systems are unable to recognize novel utterances, training systems that employ voice input will encourage the use of the prescribed brevity codes.

Computer Monitored Voice Communciations

The proposed method for incorporating computer-monitored voice communications in computer-based team training is to use the computer as an intelligent transmission medium. Figure 1 sketches the transmission function of such a system. Student team members are auditorily isolated from each other. A student claims the transmission line by depressing a switch. The computer system then

loads into the voice recognition unit the student's prerecorded vocabulary and then signals the student that the voice line is available. The student speaks in voice brevity code, which the voice input system recognizes and passes to the computer program. If there is a failure to recognize, the system prompts the student to repeat. When a recognizable utterance is produced, the system itself speaks this utterance to the addressee, using a voice output device.

This approach offers a number of advantages to one in which a computer voice input device attempts to monitor the free exchange of verbal communications between two speakers. One advantage is that nothing can be transmitted from a speaker to a listener without the computer first recognizing the utterance. Thus communication is strictly controlled. This means that all team communication is accurately monitored by the system. A second advantage is that the use of voice brevity codes is strictly enforced. Students will quickly learn that fellow team members can only hear messages phrased in voice brevity codes. Such a training system will promote the acquisition of brevity code communication habits early in training.

There are potential disadvantages to this training approach, which should be explored empirically. The first potential problem is that the interposition of a delay in voice transmission, due to the system's recognition and relay times, may be long enough to

restrict the effectiveness of voice communication. Another possiblity is that the strict enforcement of the use of voice brevity codes may hurt performance.

If computer-relayed voice communications prove effective in team training, several special applications of the technique deserve detailed exploration. One such application is individual team member training by the computer-based training system. If team members are isolated from each other in the training configuration, it may be very easy for the training program to emulate certain members of the team for the purpose of individually training other members of the team. If the emulation behaves in the same manner as actual team members in terms of the transmitted voice codes and the decisions taken, student trainees should not be able to tell whether they are interacting with the program or with other students.

A variety of experiments are called for to explore the consequences of computer-relayed voice communications in team training. At least two issues must be addressed by such experiments. The first issue is whether the use of computer-relayed voice causes significant deterioration in performance on the task and on learning. The second issue is whether computer-monitored voice can be productively employed to promote more effective training through adaptive system responses to student voice input. That is, can a CBT system take advantage

of its monitoring of vocal interchanges to provide more effective instruction?

Programs have been prepared to conduct an experiment to answer this question. Teams of two students work on simulated gunnery problems in a context similar to the Air Defense game used for the experiment described above. In the new version of the game, one team member acts as a radar operator, who observes the radar screen and decides when a missle should be fired and at what bearing. The radar operator passes these instructions to the second student, who plays the role of the missle operator or gunner. The gunner fires missles by keying in the bearing sent by the radar operator.

In one condition of this experiment the radar operator gives his instructions directly to the gunner by voice. In the other condition, the radar operators voice instructions are intercepted by the voice recognition device, understood, and then relayed to the gunner by means of a voice output device. In both cases the gunner responds by keying in the attack bearing and depressing the "fire" key.

The extent to which the computer-monitored voice transmission group performs less well than the direct voice communication group will serve as a measure of the difficulty imposed by the use of computer voice I/O in this type of training.

Modeling the Acquisition of Complex Dynamic Skills

Intelligent training systems of the future may be ubiquitous. Certainly, they will be cost effective, providing their software can be made as intelligent as we expect. One important aspect of providing intelligent instruction is having a reasonable understanding of the student. Research is called for to develop a general theory of skill acquisition and a method for the representation of knowledge about dynamic tasks. A training system that embodies such a theory should be better able to understand the student than one that does not.

Other benefits can be expected from a coherent approach to the representation of dynamic skills. One example is that computer based monitoring of actual skill performance in the field could be made possible, using realistic models of the performers' skills and knowledge states relevant to the task. The monitor program would evaluate the performance in terms of a model of the user built up in the course of his or her performance. Another possibility is that when a new dynamic skill task is designed (as, for example, in the creation of a new type of vehicular control system), the performance characteristics of the task could be modeled using this system.

A procedural semantics format can be employed for the representation of dynamic skill knowledge. This representation

format has the advantage that it is designed for implementation in a computer simulation of a student's mental processes in dynamic skill performance.

Two alternative approaches can be developed to produce descriptions of students' understandings of the components of the task. These descriptions will be used to produce student-specific models of the task, which will drive simulations of student performance. A describe-simulate-verify cycle will be used to fine-tune student descriptions to create accurate simulations of student performance. Repetitions of this process of modeling indvidual student's acquisitions of a dynamic skill throughout the course of instruction will be used to explore the nature of skill acquisition in general. The products of this research will be a tested representational format for dynamic skills and related knowledge, a set of methods for creating and validating such representations, and a model-theoretic description of the mechanisms of skill learning. A notable potential application for these research products is a method for creating models of the student for use in intelligent computer-based dynamic skill training systems.

The most important products of the research will be models of the skills and knowledge required by such complex tasks and a theory of the nature of the learning process for these tasks. Major portions of this theory will be implemented in a computer

model of the skills and knowledge required by a complex dynamic skill. A theory of how novice students develop and modify these skill and knowledge representations will also be developed. The representations will be expressed as schemata within the framework of procedural semantics. Eventually this type of representation should play an important role in intelligent computer based instruction of dynamic skills.

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Analysis of Variance

Group means for first analysis.

Keyboard	88.933
Voice	-24.40

Source	Sum of Squares	df	Mean Square	F Ratio
Between	96333.300	1	96333.300	3.682
Within	732559.000	28	26162.800	
Total	828892.000	29		

Table 1. Voice Input in Training Experiment. Summed scores for two training sets.

Analysis of Variance

Group means for second analysis.

Keyboard	54.067
Voice	8.867

Source	Sum of Squares	df	Mean Square	F Ratio
Between	15322.800	1	15322.800	2.507
Within	171165.000	28	6113.020	
Total	186487.000	29		

Table 2. Voice Input in Training Experiment. Final training scores.

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